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Robust Modulo Remaindering and Applications in Radar and Sensor Signal **Processing**

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14. ABSTRACT

This report describes the main research achievements during the time period cited above on the research project in the area of digital signal processing. The main achievements include robust reconstruction of large integers (one or two simultaneous integers) from their remainders/residues modulo several moduli, and the maximal dynamic range for the determinable integers of two from their remainders modulo a set of moduli. It includes their applications in phase un-wrapping in SAR imaging of moving objects, high frequency determination from multiple undersampled signals with very low sampling rates of sensors, and error correction coding. This report also includes a new OFDM SAR imaging by using sufficient cyclic prefix (CP) at transmitter and a non-matched filter imaging algorithm at receiver called inter-range-cell interference (IRCI) free range reconstruction.

15. SUBJECT TERMS
Robust Chinese remainder theorem, generalized Chinese remainder theorem, undersampling, SAR imaging, phase unwrapping, OFDM SAR, MIMO-OFDM SAR

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Main accomplishments:

To robustly reconstruct a large integer from its several much smaller erroneous remainders modulo a set of moduli,we obtained a robust Chinese remainder theorem (CRT) for a general set of moduli with a new necessary and sufficient condition on the remainder errors, where the moduli after factorizing their greatest common divisor (gcd) may not be necessarily co-prime. This can be thought of as a single stage robust CRT. We also obtained a two-stage robust CRT by grouping the moduli into several groups as follows. First, the single stage robust CRT is applied to each group. Then, with these robust reconstructions from all the groups, the single stage robust CRT is applied again across the groups. Interestingly, with this two-stage robust CRT, the robust reconstruction holds even when the remainder error level is above the quarter of the gcd of all the moduli that is state of the art bound for the single stage robust CRT. Therefore, the two-stage robust CRT further improves the robustness of the single stage CRT. General multi-stage CRT was also proposed. This newly obtained robust CRT has been applied in range estimation in sensor networking etc. We also obtained space-time Radon-Fourier transforms for radar target detection.

We obtained the maximal determinable range for two integers from its multiple remainders modulo a set of moduli and a new fast determination algorithm for two integers from their multiple remainders. We have also obtained a robust reconstruction algorithm for polynomials from their remainders modulo several moduli polynomials and found its applications in error correction coding. We have obtained robust channel-calibration algorithms for multi-channel in azimuth HRWS SAR imaging, which can better accommodate flight trajectory errors in high resolution and wide swath width SAR imaging. SAR imaging using orthogonal frequency division multiplexing (OFDM) signals has existed for a while by borrowing the OFDM concept from the telecommunications literature, where OFDM signals have been just treated as the conventional radar waveforms and their most important feature of intersymbol interference (ISI) (corresponding to inter-range cell interference free (IRCI)) free has not been utilized. We have obtained a new OFDM SAR imaging including new OFDM signal design and new SAR imaging algorithm so that there is no IRCI and therefore it can achieve a super range resolution in a SAR image. We have also obtained a new sparse reconstruction algorithm in ISAR imaging for rotating targets.

We also obtained a maximum likelihood estimation (MLE) based robust CRT that has a fast algorithm that only needs to search for the solution among L elements, where L is the number of remainders and the noisy remainders follow wrapped Gaussian distributions. Then, a necessary and sufficient condition on the remainder errors for the MLE CRT to be robust was obtained. We proposed a new CP based OFDM radar signal design for the IRCI free range reconstruction SAR imaging, where the zero head and tail property is proposed at the first time, in addition to the low peak-to-average power ratio (PAPR) in both the time and the frequency domains. We obtained MIMO-OFDM SAR imaging with sufficient CP. With our obtained MIMO-OFDM radar, it achieves IRCI free range reconstruction, collect the full spatial diversity from all the MIMO antennas, and maintains the same range resolution as that in a single antenna radar with the same total bandwidth. We obtained a new MIMO-OFDM radar using circularly shifted Zadoff-Chu sequences.

Refereed journal publications (published) during the reporting period:

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Abstract

We also obtained a maximum likelihood estimation (MLE) based robust CRT that has a fast algorithm that only needs to search for the solution among L elements, where L is the number of remainders and the noisy remainders follow wrapped Gaussian distributions. Then, a necessary and sufficient condition on the remainder errors for the MLE CRT to be robust was obtained. We proposed a new CP based OFDM radar signal design for the IRCI free range reconstruction SAR imaging, where the zero head and tail property is proposed at the first time, in addition to the low peak-to-average power ratio (PAPR) in both the time and the frequency domains. We obtained MIMO-OFDM SAR imaging with sufficient CP. With our obtained MIMO-OFDM radar, it achieves IRCI free range reconstruction, collect the full spatial diversity from all the MIMO antennas, and maintains the same range resolution as that in a single antenna radar with the same total bandwidth. We obtained a new MIMO-OFDM radar using circularly shifted Zadoff-Chu sequences.

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Archival Publications (published) during reporting period:

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1) H. M. Wang, Q. Yin, and X.-G. Xia, Distributed Beamforming for Physical-LayerSecurity of Two-Way Relay Networks, IEEE Transactions on Signal Processing, vol. 60, no. 7, pp. 3532-3545, July 2012.

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Changes in research objectives (if any):

Change in AFOSR Program Manager, if any:

The program manager has been changed from Dr. Jon Sjogren to Dr. Tristan Nguyen and then to Dr. Arje Nachman

Extensions granted or milestones slipped, if any:

AFOSR LRIR Number

LRIR Title

Reporting Period

Laboratory Task Manager

Program Officer

Research Objectives

Technical Summary

Funding Summary by Cost Category (by FY, $K)

	Starting FY	FY+1	FY+2
Salary			
Equipment/Facilities			
Supplies			
Total			

Report Document

Report Document - Text Analysis

Report Document - Text Analysis

Appendix Documents

2. Thank You

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